New Ignition Mechanism in Oxygen-enriched Environment: Spontaneous Combustion

Joel M. Stoltzfus, *White Sands Test Facility*
Timothy D. Gallus, *White Sands Test Facility*

After a fire occurred overseas in an Expeditionary Deployable Oxygen Concentration System (EDOCS) unit used by the U.S. Air Force, the NASA Johnson Space Center's White Sands Test Facility (WSTF) Oxygen Group was requested to perform a failure analysis to determine the fire's cause. The EDOCS is a portable oxygen concentration system used to supply concentrated oxygen for medical purposes.

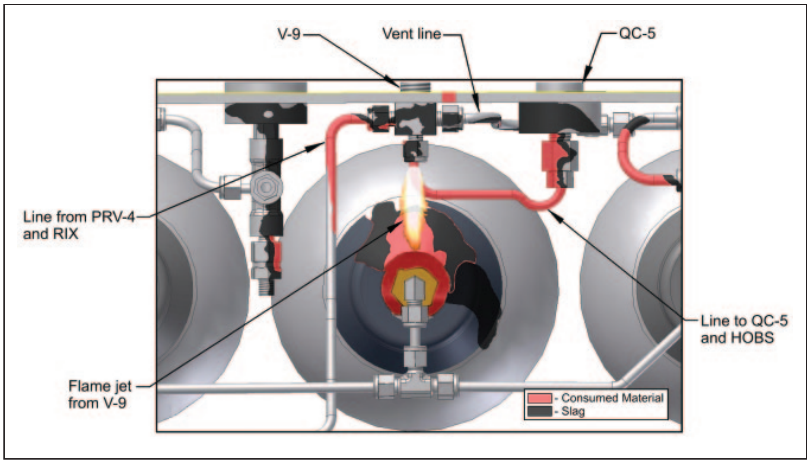

Fig. 1. *Flame jet from V-9 impinging on carbon steel cylinder u-bolt and cap.*

The failure analysis performed at WSTF ruled out all currently understood ignition methods as the cause of the fire. Instead, through inspection and analysis, the WSTF Oxygen Group determined a newly observed ignition mechanism most likely caused the fire event: spontaneous combustion. With results from the failure analysis, the group surmised that a leak of high-pressure, oxygen-enriched gas across the silicone-lubricated, polytetrafluoroethylene (PTFE)-encapsulated seat or ball of the V-9 (figure 1) valve was the initiating cause of the fire that subsequently burned through the downstream 90-deg bend in the 0.64-cm- (0.25-in.)-diameter stainless steel hardline. It was concluded that the fire jet from the burned hardline impinged the nearby cylinder containing oxygen-enriched gas near its top, igniting the carbon steel (figure 1). Oxygen rushing from the burned hardline fed the burning stainless steel until it failed, causing the release of its contents in a sudden, destructive flame jet that damaged many nearby components in the oxygen system.

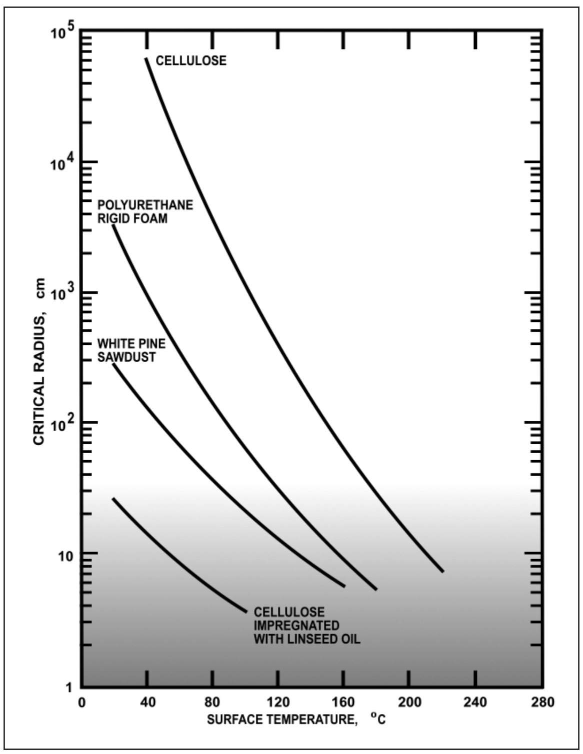

Fig. 2. *Critical radius of oil-soaked cellulose particles as a function of surface temperature in air.*

During the investigation, the group observed cellulose fibers in a 0.64-cm (0.25-in.) hardline in the system upstream of V-9. It was apparent that the hardline had not been properly de-burred during manufacture and that the cellulose fibers were snared in the stainless steel burrs formed during cutting of the tubing. It is surmised that cellulose particles accumulated near the leak path in V-9 between the PTFE capsule and ball, and were soaked with silicone-based lubricant. The result of accumulations of cellulose particle and fiber material being coated with silicone oil in pressurized oxygen-enriched gas was to decrease their ignition temperature as the size of the accumulation grew. If the accumulation of silicone-soaked cellulose particles reached a critical diameter of 0.08 cm (0.32 in.), the particles could spontaneously ignite with no external energy input. If the accumulation were of a smaller diameter, then energy from one of the other heat sources present during system operation would be needed to raise the cellulose contaminant to its ignition temperature.

The autoignition temperature of an accumulation of cellulose fibers and particles is dramatically affected by the radius of the deposit of particles. Oil-impregnated cellulose will ignite in air at 100°C (212°F) if the radius of the accumulated deposit of particles reaches 4 cm (1.6 in.) (figure 2). If it is assumed that the critical diameter decreases directly as a function of the oxygen concentration, then the critical radius in 95% oxygen at 2200 psi would be [4 cm x (14.7 psi/2200 psi) x (21% oxygen/95% oxygen) =] 0.006 cm (0.002 in.). In addition, it is observed that if the diameter of the accumulated deposit of cellulose particles is increased to [27 cm x (14.7 psi/2200 psi) x (21% oxygen/95% oxygen) =] 0.04 cm (0.016 in.), then the autoignition temperature of the oil-soaked cellulose is 20°C (68°F).

In the EDOCS fire, it is surmised that cellulose particles accumulated between the PTFE seat capsule packing and the stainless steel seat or ball and reached the critical diameter that would cause spontaneous ignition of the particles. It is postulated that the burning cellulose particles ignited the PTFE seat packing and burned downstream to the edge of the stainless steel seat or ball. As the flame impinged the sharp corner of the stainless steel seat or ball, it was ignited (Location A in figure 3). The burning proceeded downstream, out of V-9, into the connecting stainless steel tube and out through the 90-deg bend, producing the flame jet seen in figure 1.

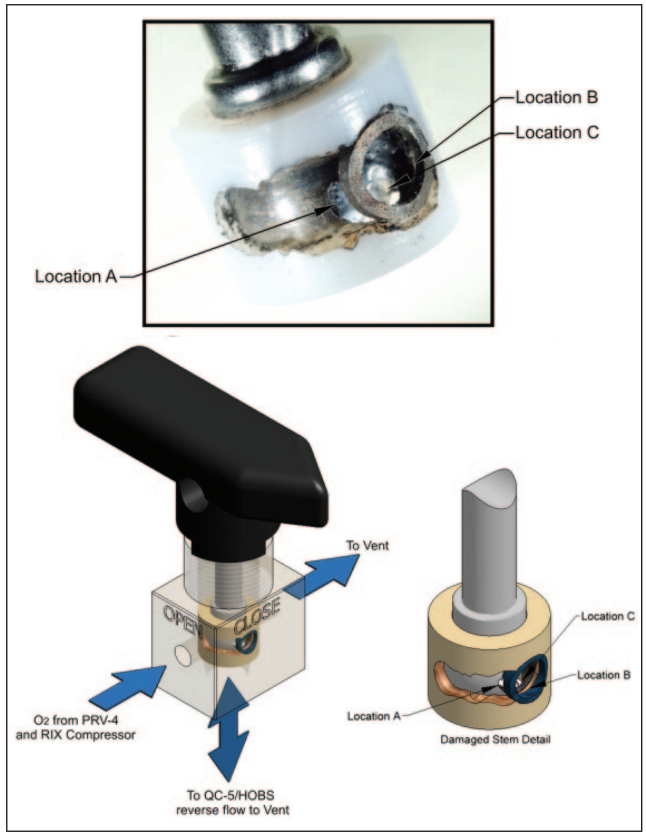

Fig. 3. Damaged stainless steel valve stem/polytetraflourethylene capsule seat packing from V-9. (See Location A.)

In conclusion, a previously unobserved ignition mechanism in oxygen-enriched environments has been postulated as the best explanation of a fire in a pressurized system. Of all the possible ignition mechanisms, spontaneous combustion of silicone oil-soaked cellulose particles in a leaking valve is the most likely to have caused the fire. As funding becomes available, the WSTF Oxygen Group will develop a test to recreate and validate this proposed ignition scenario. Data from this test will enhance designers' ability to control fire hazards in oxygen-enriched environments.